HEARING PROTECTION'S COMFORT EVALUATION IN THE LABORATORY

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1 Introduction

Hearing Protection Devices (HPDs), such as earmuffs and earplugs, are used to protect workers exposed to high noise levels in their work environment. Since HPDs tend to not be comfortable, they are not worn at all or not worn consistently or correctly [1]. In a recent literature review dedicated to HPDs, the global perception of HPD comfort is defined as a balanced measure of four dimensions (physical, acoustical, functional, and psychological) that characterize the relationship between the user and the HPD in the work environment [1]. Most laboratory studies related to the perception of HPDs comfort did not study the effect of the noise of the environment because the associated tests were carried out in a quiet environment [2]. Only one special and constant noise was used for two laboratory studies on HPDs comfort [2] that were carried out in a noisy environment and the results cannot be generalized because the characteristics of this noise remained the same for all the tests of these studies.

This laboratory study focuses on the evaluation of earplugs comfort because: (1) they are the most used protectors in the field, (2) they provide less reliable protection than earmuffs, as it is more difficult to position them correctly in the ear canal, and (3) earmuff's comfort has already been studied in the literature using both subjective and objective approaches [1, 2]. The main objectives of this work are to (1) evaluate the global perception of the comfort of earplugs, and (2) study the effect of the sound environment on the four dimensions of comfort (physical, acoustical, functional, and psychological).

2 Method

2.1 Reproduced sound environments

Two virtual industrial environments that served as background noise during this study, were generated using multichannel Acoustic Background Spectrum (ABS) synthesis [3], and *in-situ* recordings collected at two different workstations in two industrial organizations using a stacker (environment 1) and a granulator (environment 2). A square array of 96 loudspeakers was used to recreate the virtual sound environments in a 4m × 4m space. The first sound environment was calibrated at 90.9 dB (SPL) and the second one at 93.0 dB (SPL) [3].

2.2 Participants and hearing protectors

A sample of 24 naive (inexperienced regarding hearing protectors), normal-hearing participants, having hearing thresholds below 25 dB HL, tested three different earplugs in the two different reproduced sound environments. The earplugs used by the participants were either roll-down foam earplugs (3M™ E-A-R Classic), premolded earplugs (3M™ E-A-R UltraFit), or push-to-fit foam earplugs (3M™ E-A-R Push-ins), which are an alternative between the roll-down foam and the premolded earplugs.

2.3 Laboratory tests

The laboratory tests were performed in three measurement sessions. In each session, the participant tested one earplug chosen randomly from the three earplugs in the two sound environments also chosen randomly. During the tests, the participant had to complete a simulated work task (moving boxes in the region surrounded by the reproduction loudspeakers). For each sound environment, the participant was asked to complete alarm detection tests, speech in noise detection tests, and answered questionnaires to assess HPDs comfort. Those tests were carried out while the participant wore the earplug.

2.3.1 Alarm detection tests

Alarm signals were presented at five different signal-to-noise ratios (SNRs) relative to the reproduced background noise, from -10 dB (most difficult) to +10 dB (easiest) with a 5 dB step.

2.3.2 Speech in noise detection tests

A total of 60 stimuli (4 stimulation levels × 15 repetitions) consisted of sentences pronounced in French were presented to the participants in random order. The stimulation levels were calibrated to 62.4, 68.3, 74.9, and 82.3 dB (SPL), which correspond respectively to the level of normal, raised, loud, and shouted voice [4].

2.3.3 Subjective questionnaires

Participants answered a set of questionnaires, which is an adapted version of the COPROD questionnaire (COnfort

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des PROtections auDitives/COmfort of hearing PROtection Devices) [5].

The purpose of these questionnaires was to evaluate the attributes of the four mentioned dimensions of earplug comfort as well as the overall comfort.

2.4 Statistical analyses

Statistical analyses were carried out on the data collected during the tests below using the SPSS software (Statistical Package for the Social Sciences) and R 3.6.1 with MASS 7.3–51.4. The objective of these analyses was to determine the influence of the earplug model and sound environment on the perception of comfort.

3 Results

3.1 Alarm detection tests

Alarms presented with the highest stimulation levels were always heard by the participants, while the participants were not able to hear clearly alarms presented with the lowest stimulation level. Moreover, sound environment 1 had the lowest detection scores at a low stimulation level (SNR = -15 dB) compared to sound environment 2 for the three earplugs. Therefore, the sound environment has an effect on alarm detection when the task is difficult (SNR = -15 dB).

3.2 Speech in noise detection tests

For the normal and raised voice (difficult conditions), it was impossible for the participants to discriminate the speech from the noise. Thus, when the task was difficult, the speech was never understood. Speech detection is thus affected by the sound environment when the task is difficult.

For the loud and shouted voice (easy conditions), participants were able to discriminate speech from noise with more or less success depending on the sound environment. Mostly, and despite the fact that the SPL was larger for sound environment 2, it had higher speech detection scores compared to sound environment 1.

3.3 Questionnaires on comfort perception

Comparative analyses were performed to evaluate, according to the earplug family and the sound environment, the perception of physical, functional, acoustical, and psychological comfort in relation to the general items (for each dimension of comfort from the COPROD - NAQ).

Results showed no differences in comfort for the three tested earplugs, except for functional comfort. More specifically, push-to-fit foam earplugs were considered more functional while roll-down foam earplugs were less functional.

Results showed a significant effect of the sound environment on participants' perception of hearing useful sounds (alarm signals). More specifically, sound environment 2 allowed to better hear the alarm signals compared to sound environment 1.

4 Discussion and conclusion

Sound environment 2 has less energy than sound environment 1 in the frequency ranges from 562 Hz to 6300 Hz. On the other hand, both speech and alarm signals have their maximum energy in this frequency range. Such differences contributed to an increase in the masking effect induced by sound environment 1 on the alarms and the speech signals. Moreover, the earplugs' contribution to the masking effect remained the same and cannot explain the difference observed in the results obtained in the two sound environments, because the participants were instructed to never remove their hearing protectors during the whole experience, which means that the attenuation provided by the earplugs remained the same throughout the experience.

When the speech comprehension task is difficult ("raised voice" and "normal voice" conditions), the masking effect created by the background noise is large enough that it prevents participants from understanding the speech, regardless of the sound environment. Since sound environment 2 has less energy than sound environment 1 in the same frequency range, the masking effect induced by environment 2 on the speech stimuli is less problematic than the one induced by environment 1.

To conclude, earplugs' perceived comfort is affected by the type of earplugs and the frequency content of the sound environment.

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